(Reprinted from Transactions of the American Geophysical Union,
Seventeenth Annual Meeting, 1936)

AMERICAN GEOPHYSICAL UNION

Seventeenth Annual Meeting

SECTION OF SEISMOLOGY, AMERICAN GEOPHYSICAL UNION
AND
EASTERN SECTION OF THE SEISMOLOGICAL SOCIETY OF AMERICA

Washington, D. C.
May 1 and 2, 1936

Reports and papers

PROGRESS-REPORT ON A THREE-COMPONENT SEISMOMETER AND TILTMETER

L. B. Slichter

A recently completed 3-component portable seismometer and tiltmeter of compact design was shown and discussed. This instrument is one of a number which are being constructed for the observation of ground-motions from artificial explosions. Testing of the first model is now in progress. The instrument gives promise of being sufficiently sensitive and reliable for use at observatories, and for recording tilt-phenomena. In the design, special attention has been given to the matter of reducing thermal effects, and of maintaining stability of adjustment.

The following are the main data concerning these instruments: Period, about 2 seconds; damping, magnetic; pendulum-length, 13 cm; pendulum-mass, 2500 grams; static magnification, selectable in the range 80 to 25,000. Variation in static magnification is obtained by changing either the optical lever or the mechanical magnification-element or both. The mechanical magnification-element is a modification of Taylor's design. This, because of its symmetry, is theoretically balanced against thermal and elastic errors. Electrical calibration-coils are built into the instrument for the convenient determination of the dynamic constants and scale-factor. Electrical control of the zero-position of the light-spot is also provided. In the vertical component a Chatillon isoelastic spring of LaCostes' zero-length design is utilized.

Massachusetts Institute of Technology,
Cambridge, Massachusetts

PROGRESS-REPORT ON THE RESEARCH CONNECTED WITH THE TIMISKAMING EARTHQUAKE OF NOVEMBER 1, 1935

Ernest A. Hodgson

The paper reported the details of the location of the epicenter of this earthquake by means of the arrival-times at seven seismological stations, most of which were within 400 miles of the epicenter. The field-work confirmed the location so deduced. Details of that work were given.

The location was based on the use of the graphs recently published by Brunner and assumed a focal depth of 200 km (125 miles). All the evidence from the field was in accord with this deduction.

Records of this earthquake were requested and have been coming in ever since. All available are now probably in hand and a study of them has been begun. They do not altogether support the assumed focal depth. The P-phases, etc., are not generally in evidence but most of the records show the large S-waves and small L-waves characteristic of deep-focus earthquakes. This phase of the subject is to be studied with care.

The writer proposes to fly over the epicentral area in the near future as soon as the ice is gone from the lakes. The gravel-banks bordering the many lakes were cracked at the time of the earthquake. The ice of winter will undoubtedly cause small landslides. It is proposed to see what the distribution of these may be.

It is hoped that a gravity-station will be established at Timiskaming and that three of the stations occupied previously about the area will again be visited.

Dominion Observatory,
Ottawa, Canada

CURRENT GEOPHYSICAL ACTIVITY IN TEXAS AND LOUISIANA

Donald C. Barton

(Abstract)

The geophysical activity in Texas and Louisiana at the present time is as follows: Seismograph crews in the Gulf Coast, 77; in east Texas, 13; in north Texas, west Texas, and southeast New Mexico, 6; total, 96. Torsion-balance crews in the Gulf Coast, 32; in east Texas, 1; in north

Texas and west Texas, 3; total, 36. Magnetometers, 7. Gravimeters, 7 (all in the Gulf Coast). Pendulum crews, 3 (all in the Gulf Coast). Experimental electric crews, 2. The grant total of all types of geophysical crews is 151.

Humble Oil and Refining Company,
Houston, Texas

PROGRESS-REPORT IN SEISMOLOGY FOR THE UNITED STATES COAST AND GEODETIC SURVEY

E. W. Eickelberg

The routine work of the Coast and Geodetic Survey in seismology was quite well established by the time of the last meeting and is outlined in the report of the Section of Seismology (pp. 96-99, Transactions of 1935). Only changes and additions in this part of the work will be mentioned. The same abbreviations will be used as in that report: MIT for Massachusetts Institute of Technology; CGS for Coast and Geodetic Survey; JSA for Jesuit Seismological Association; CIW for Carnegie Institution of Washington; Cal-Tech for California Institute of Technology; SRL for Seismological Research Laboratory; UC for University of California; NBS for National Bureau of Standards.

Earthquake information--There has been little change. Special mention should be made of the work of W. E. Maughan, Assistant Meteorologist in charge of Weather Bureau Office at Helena, Montana, who kept the record of the more than 1800 shocks that have occurred in the series that began October 3, 1935, and is still in progress (93 shocks during March). He also cooperated by looking out for the strong-motion instrument left at Helena by request when the CGS personnel was obliged to return to duty in California. In California the number of reports has fallen off somewhat more than the earthquake-activity. This is in part due to the lack of adequate personnel to take care of data when obtained. Plans are being worked out between CGS and UC to improve this situation. There is ample opportunity for addition to the service for the country as a whole.

Teleseismic work--The following additions have been made during the year. The station at College, Alaska, was put into operation November 15, 1936. Professor E. H. Bramhall of the University of Alaska is supervising its operation, in addition to having made the installation. A station at Butte, Montana, was made possible by loan of one component of a Wood-Anderson instrument by Dr. Day, Chairman of the Advisory Committee in Seismology of the CIW, and of recorder and other accessories by CGS, the site and installation and servicing being by the Montana School of Mines. The Jamaica Station has been equipped with a Wood-Anderson seismometer, loaned by the CIW, and with a recorder loaned by Georgetown University.

Immediate location of epicenter was carried out for 23 earthquakes. There have been no changes in the plan for immediate determination of epicenters except that St. Louis now informs Science Service as to probable accuracy of their determination of epicenter.

Recording of strong earth-motion and related activity--The important feature of the year's strong-motion work was the emergency installation of an accelerograph at Helena, Montana, October 21, 1935, which resulted in a large number of strong-motion records. Some of these were complete, that is, the recorder was in operation when the earthquake occurred so that no part of the record was lost through delay in action of starter. The activity was moderate in the California Region and only eight strong-motion records were obtained of five earthquakes.

The program of measuring the vibration-periods of buildings, tanks, bridges, dams, and of the ground was greatly curtailed during the year as funds became exhausted and this part of the work is now largely cooperative, especially with Stanford University, and is applied to special problems. Fortunately, it has been possible to publish most of the results of the special work in this field and this will soon be available.

Records of interest during the past year--The most interesting records of the year were those obtained of the series of Montana earthquakes. Though the series started on October 3, 1935, and there was a destructive earthquake October 18, the instrument was not installed until October 21. The most important of the records obtained were those of the destructive earthquake of October 31 and strong aftershocks of November 28, 1935, and February 23, 1936. There were a number of records obtained while the recorder was in operation so that the entire shock was recorded. It has been definitely demonstrated by actual records that earth-movements are different for every earthquake, which makes necessary indefinite continuation of the obtaining of records.

Instrumental developments--The records of the Montana earthquakes were vastly superior to those of the Long Beach, California, earthquake of 1933 and this is due to the continuous improvements of instruments since that time. In the case of Montana it was necessary to improvise a starting device responding to vertical motion and this has since been improved. Plans have been worked out for setting up an accelerograph in open country as, for example, in the case of an earthquake in an unsettled region such as the Nevada earthquake of December 20, 1932.

Work on shaking table at National Bureau of Standards for tests of high-magnification seismographs was completed and the platform has been dismantled. The results were in part presented by Dr. Frank Wenner of NBS and H. E. McComb of CGS before the Philosophical Society of Washington, but they have not yet been published.

Crustal movements--Plans have been made for precise levels in the vicinity of Helena, Montana, a party being in the field at the present time.

Work has been done in California as follows: The Merritt tiltmeter has been in operation at UC. With the aid of a grant from the National Research Council, Mr. Merritt has developed a recording device which gives hourly records and this has been given a thorough test. There have been no earthquakes on the Hayward Fault during the period and there have been no tiltmeter records such as have been found in Japan to be characteristic of earthquakes.

Utilization of results--Strong-motion records have been in demand as well as their interpretation, especially the derivation of displacement-curves from accelerograms by the double-integration method developed by Mr. Neumann of CGS. These records have been used by Mr. Ruge of MIT to operate a shaking table on which are tested models of tanks and other structures, the motion of the ground during the earthquake being impressed upon the platform by a photoelectric method. There has been demand for information from those responsible for the construction of great dams and bridges as well as other structures.

Publications--"United States earthquakes for 1933," which was issued during the year, was the first issue of this series to contain strong-motion results, one-half of the number being devoted to this class of work. "Earthquake investigations in California, 1934-1935" is a special publication now in press and almost ready for distribution, describing the work of the various parties of the CGS engaged in seismological investigations, and containing a large amount of vibration-data of special interest to engineers.

Mimeographed reports issued during the year included periodic progress-reports on the California work, quarterly reports on non-instrumental results for the Pacific Coast Region, monthly instrumental reports on teleseismic work, and preliminary epicenter-results.

The following is a list of the seismograph-stations of the United States. Those stations marked with a plus (+) sign have, during the past year, sent immediate information for the determination of preliminary epicenters in cooperation with Science Service.

Seismograph-stations of the United States

Location	Supporting organization	Symbol on map as
Alabama		
Silver Hill (near Mobile)	Silver Hill College	Jesuit
Arizona		
+Tucson	Tucson Magnetic Observatory, CGS	Coast and Geodetic Survey
Arkansas		
Little Rock	Little Rock College	Jesuit
California		
+Berkeley	UC	Independent
Ferndale	J. Bognuda, cooperating with UC	Independent
+La Jolla	SRL	Independent
Mineral	Lassen Volcano Observatory, U. S. Geological Survey	Independent
Mt. Hamilton	Lick Observatory Seismological Station, UC	Independent
+Mt. Wilson	CIW	Independent
Palo Alto	Stanford University and UC	Independent
+Pasadena	SRL	Independent
Point Loma	Theosophical University	Inactive
+Riverside	CIW-City of Riverside	Independent

Seismograph-stations of the United States--Continued

Location	Supporting organization	Symbol on map as
California--Concluded		
Santa Barbara	CIW-Santa Barbara Museum of Natural History	Independent
Santa Clara	Santa Clara University	Jesuit
San Francisco	California Academy of Science	Independent
+Ukiah	CGS	Coast and Geodetic Survey
+Tinemaha	SRL	Independent
+Haiwee	CIW	Independent
Colorado		
Denver	Regis College and JSA	Jesuit
Connecticut		
New Haven	Yale University	Inactive
District of Columbia		
+Georgetown	Georgetown University	Jesuit
Illinois		
Chicago	Loyola University	Jesuit
+Chicago	CGS-U. S. Weather Bureau	Coast and Geodetic Survey
Iowa		
+Des Moines	Seeburger Seismograph-Station	Independent
Kansas		
Lawrence	University of Kansas	Proposed
Louisiana		
New Orleans	Loyola University	Jesuit
Maine		
+Technology	MIT	Independent
Maryland		
Woodstock	Woodstock College	Jesuit
Massachusetts		
+Cambridge (Oak Ridge)	Harvard University	Independent
Weston	Weston College	Jesuit
Worcester	Holy Cross College	Jesuit
Williamstown	Williams College	Independent
Michigan		
+Ann Arbor	University of Michigan	Independent
Missouri		
Florissant	St. Louis University	Jesuit
+St. Louis	St. Louis University	Jesuit
Montana		
+Bozeman	Montana State College and CGS	Coast and Geodetic Survey
Butte	Montana School of Mines, CIW, and CGS	Independent
Nevada		
Reno	University of Nevada	Independent
New York		
Albany	University of State of New York	Inactive
+Buffalo	Canisius College	Jesuit
+Ithaca	Cornell University	Independent
+New York	Fordham University	Jesuit
New York	Museum of Natural History	Independent
Ohio		
+Cincinnati	St. Xavier College	Jesuit
Cleveland	John Carroll University	Jesuit
Pennsylvania		
+Pittsburgh	University of Pittsburgh	Independent
+Philadelphia	Franklin Institute	Independent
+State College	Pennsylvania State College	Independent
Swarthmore	Swarthmore College	Inactive
South Carolina		
Columbia	University of South Carolina-CGS	Coast and Geodetic Survey
Texas		
Denton	John W. Crain	Independent
Utah		
Salt Lake City	University of Utah	Independent
Vermont		
+Burlington	University of Vermont	Independent

Seismograph-stations of the United States--Concluded

Location	Supporting organization	Symbol on map as
Virginia		
+Charlottesville	University of Virginia	Independent
Washington		
Seattle	University of Washington	Independent
Spokane	Gonzaga University	Jesuit
Wisconsin		
Milwaukee	Marquette University	Jesuit
+Madison	University of Wisconsin	Independent
Nebraska		
Lincoln	Nebraska Wesleyan University	Proposed

In addition to those stations marked with a plus sign in the above list there are a number of stations outside the United States which have cooperated in sending immediate information for the determination of preliminary epicenters. These are listed below:

Manila Observatory, Manila, Philippine Islands
Dominion Meteorological Observatory, Victoria, British Columbia, Canada
Royal Observatory, Hongkong, China (via Manila)
l'Observatoire de Zi-Ka-Wei, Zi-Ka-Wei, China (via Manila)
University of Hawaii, Honolulu, Territory of Hawaii
Magnetic Observatory, CGS, Sitka, Alaska
Magnetic Observatory, CGS, San Juan, Puerto Rico
University of Alaska, College (near Fairbanks), Alaska
Observatorio del Ebro, Tortosa, Spain (through St. Louis University, St. Louis, Mo.)
The Observatory, Apia, Samoa
Huancayo Magnetic Observatory, CIW, Huancayo, Peru
The Dominion Observatory, Ottawa, Canada

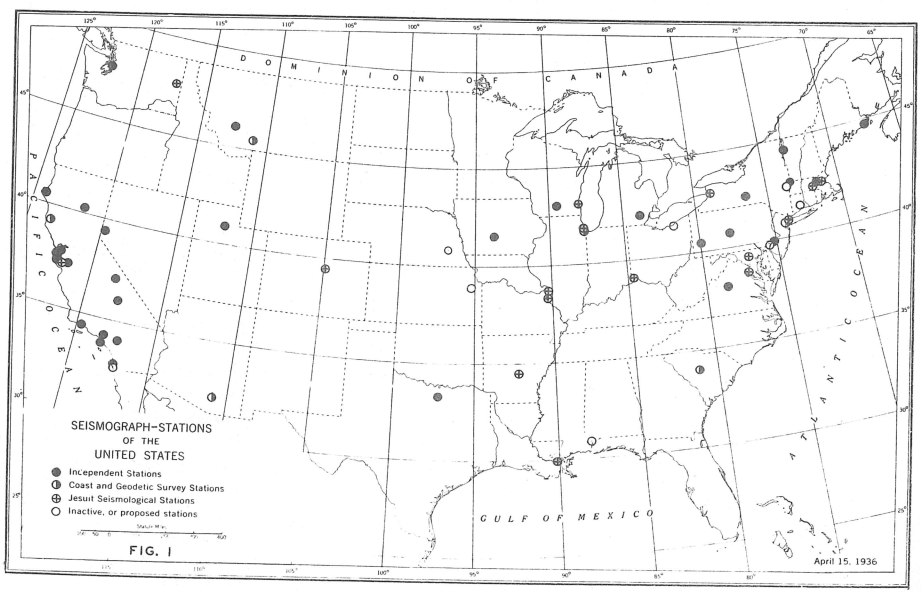

FIG. 1

U. S. Coast and Geodetic Survey,
Washington, D. C.

GEOLOGICAL IMPLICATIONS OF DEEP-FOCUS EARTHQUAKES

V. C. Stechschulte

Five years ago at the Pasadena meeting of the Seismological Society the writer ventured to state in a preliminary report of the evidence for a focal depth of 400 km for the Japanese earthquake of March 29, 1928, that the occurrence of earthquakes at a depth of 400 km may well have large significance for isostasy and related problems, as well as in regard to structure, constitution, and condition of the Earth. At that time deep foci enjoyed only a modicum of scientific respectability, but since then they seem to have found an accepted place in the family of scientific data, and interest has arisen in regard to their significance and implications. The present paper is an attempt to develop, to a little extent, some of these implications.

Probably the main difficulty against accepting the reality of deep foci lay in the fact that our picture of "ordinary" earthquakes was that of a sudden release from accumulated elastic shear, the classical example being the California earthquake of 1906. But how can you have shear at great depths? It is difficult enough to imagine shear at 50 km or even at 30 km, but it may be questioned whether it is essentially more difficult to picture it at 500 km than at 50 km. The difficulty varies in degree, not in kind. The big stumbling-block is, of course, that accepted speculation has led us to think of the rocks having zero-strength at great depths on account of the excessive temperatures presumably existing there. Here, then, we have the first and probably the most important implication of plutonic earthquakes, namely, strength at unexpected depths. However, before such a conclusion is accepted it will naturally be desired that other possibilities be eliminated. Are such shocks not due perhaps to an explosive activity of some sort? It would seem just as difficult to imagine anything akin to a gas- or dynamite-explosion taking place on the necessary large scale as to imagine shear. However, appeal must be made not to the imagination, but to the seismographic records. Here various lines of evidence present themselves.

First, from the direction of the initial movement. If the source were an "explosion," one might well expect the direction of motion of the first impulse to be generally the same, probably a compression. However, no such consistency appears. Thus of 219 shocks during the course of four years qualified in the Bulletin of the Seismological Laboratory at Pasadena as "deep," either with assurance or questionably, 127 showed the first motion as a compression and 92 as a dilation. The question has been raised in a letter to the writer whether substances might not change their state, with release of energy, but sometimes with an increase and sometimes with a decrease in volume, provided their stable conditions for temperature and pressure have been passed without change having occurred. I do not know whether such an event is to be expected or not. I should be inclined to think, however, that the changes taking place in the depths would probably be more unidirectional in character than the above-quoted figures would indicate if the suggested hypothesis were true. However, neither for a given earthquake do we find uniformity of motion at various stations, but rather compressions and dilatations scattered as we find them in the case of near-surface shocks. Kawasumi and Yosiyama (Proc. Imper. Acad., v. 6, pp. 345-348, 1934) have even gone so far as to assign, on the basis of the distribution of first motion, a definite dip and strike for the plane along which the quake of February 20, 1931, took place, whose depth, according to the study by Scrase, was about 360 km. Still, it should be said, they do not speak clearly of a fault along that plane. But whether one is prepared to accept this result or not, it would seem that the balance of evidence from the first motion tends to be against a purely explosive source.

More positive evidence of shear at the source and therefore of strength in the material is to be found in the abundance and apparent predominance of the energy carried by the shear-waves on the seismograms. Indeed, the sharpness and intensity of the onset of the transverse waves has been noted as characteristic of seismograms of deep-seated shocks. Presumably such great prominence of shear-waves connotes a shear at the source and therefore strength. But how great is this strength? The analogy of pitch fractured by a "hammer-blow" may be recalled. However, one finds difficulty in thinking of a process taking place suddenly on a large enough scale to deliver the "hammer-blow" to the depths of the Earth to give us some of the energetic deep shocks that have been recorded, and if a large enough "hammer-blow" were given, this could only be by an "explosion," and then the argument from the distribution of first motion would apply. Again, if some time is required for such volume-changes, or whatever they are, to take place on a large enough scale, it would seem that the material must have some degree of strength, and probably a fairly high degree, in order to store even for a comparatively short time the large amount of shear-energy indicated by the seismograms. As further evidence of the abundance of shear-energy at the source, one may add that ScS, the shear-wave reflected from the central core, is frequently seen recorded with rather astonishingly great amplitudes.

If now we may conclude, albeit cautiously, from the character of the seismograms of deep-focus or plutonic earthquakes to shear at depth and from shear to notable strength at depths down to 600 km and more, then at least this much would seem to follow in regard to isostasy, that we cannot have a universal and uniform level of compensation, or, at any rate, that such level cannot be at the comparatively shallow depths which have been assigned. I have said "universal" because we do not know enough as yet about the geographical distribution of deep foci. Wadati tells us of a distribution along linear zones for the deep foci near Japan. Whether something similar may show up for other regions remains to be seen. But whatever the zonal distribution, the deep shocks seem to point to deep-seated spherical inhomogeneity in the Earth, whether it be in material or thermal condition, or state of aggregation. Again, if strength at great depths be admitted, it would seem that isostatic compensation can hardly be purely local in character--at least not universally so. On the other hand, the evidence from deep earthquakes does not allow us immediately to conclude that the crust, at all parts of the globe, has large strength down to great depths.

In connection with the possible zonal distribution of deep foci, it may be recalled that, even in the small percentage of the Earth's surface that has been gravitationally surveyed, there are also zones where isostasy does not represent the facts. The question may be raised whether the long narrow strips of great negative anomalies passing over into areas of large positive anomalies discovered by Vening Meinesz in the East Indies do not indicate, as Jeffreys points out, "a strength comparable with that of the upper layers through a depth of at any rate some hundreds of kilometers." What seems to be the deepest earthquake of which we thus far have record, that of June 29, 1934, with a focal depth of about 675 km, took place, according to the epicenter adopted by the writer, in the Flores Sea in the East Indies, but in a region where Vening Meinesz indicates positive anomalies. I have recently plotted the epicenters for the last eight years as given in the International Seismological Summary, and compared them with the anomaly map given by Vening Meinesz. The epicenters do not lie for the most part along the narrow zones of great negative anomalies, but rather in the positive areas. This is certainly true, except perhaps at the westernmost end, for the elongated zones parallel to the Sumatra-Java Arc, probably less so for the zone trending north toward Mindanao. One might perhaps surmise that the deep shock mentioned above and others of shallower depth are a response to the great difference in load represented by the anomaly-gradient. Vening Meinesz, on the other hand, considers earthquakes and the disturbances of gravity as due to tectonic activity, and has elaborated his buckling hypothesis to explain the great anomalies. One might venture, however, in the light of what has been said, to question the universal validity of the principle of interpretation stated by him (Gravity-expeditions at sea, v. 2, p. 18): "We can, however, express an important rule for guiding our interpretations if we assume that the anomalous masses are only occurring in the upper layers of the Earth. This assumption is obviously probable because all our geophysical considerations converge towards the assumption that the plasticity of the materials increases when we get deeper into the Earth. So deviations will be more and more unlikely for deeper layers." On the other hand, probably many will not be ready to agree with a statement recently made in a letter to the writer: "If the deep material can build up big enough stresses to generate a first-class earthquake, it is beginning to look as if we should be trying to invent a new explanation of isostasy."

Again, if there be notable strength at great depths, and if we are to retain our traditional view that high temperature tends to destroy strength, then one feels moved to agree with De Lury (J. Geol., v. 41, pp. 748-756, 1933) in asserting that it is incorrect to project an average gradient of 30° per km linearly into the Earth, that the lowest observed gradient might perhaps be the most proper one to project, and that, in any event, there may well be very deep-seated distortions of the geoisotherms. Hence another implication of plutonic earthquakes would be in regard to the thermal condition of the Earth's interior, as also in regard to theories of convection-currents within the Earth.

In line with the above, the following paragraph from Jeffreys' book, "Earthquakes and mountains," may be quoted (pp. 164-165): "We do not know enough about the variation of radioactivity to produce a theory capable of detailed comparison with observation, but we can obtain suggestive results in general terms. We should expect, for instance, that at depths down to 600 km or so, the cooling since the Earth solidified has been considerably more below the oceans than below the continents. This is verified by the distribution of mountains around the Pacific. We have a practically continuous chain or series of chains along the western coasts of North and South America. This would be expected if the ocean-floor is the stronger, because when contraction led to yield the strength would be reached first in the weaker place, and the continental rocks would be crumpled along the ocean-margin." Perhaps bearing on the truth of the above surmise is the interesting fact that the deep-focus earthquakes from South America occur well under the continent, and among these shocks are some of the very deepest of which we have record.

Either one assumes, on account of deep-focus earthquakes occurring there, greater strength under the continents than under the oceans, and then Jeffreys' explanation would be weakened, or else there is strength at even greater depths under the ocean than the depths indicated by the sub-continental deep foci. On the other hand, many deep earthquakes occur in oceanic regions, so that the evidence is inconclusive.

One more point may be added. If there be sufficient strength at depths of 500 or 600 or even 700 km to allow the storage of shear-energy, then we must also conclude that there will still be appreciable strength well beyond those depths, for it is hardly to be expected that the shear would take place where strength has practically disappeared.

Much remains to be known still about deep-seated earthquakes, their relative frequency, their geographical distribution, whether certain depths are preferred in certain localities, what relation, if any, exists between deep foci and volcanic zones, etc. However, it is believed that the evidence already available is at least sufficient to justify the title of this paper, Geological implications of deep-focus earthquakes.

Xavier University,
Cincinnati, Ohio

PROGRESS IN ENGINEERING-SEISMOLOGY RESEARCH AT MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Arthur C. Ruge

(Abstract)

The recent research at Technology has been concentrated largely upon three important problems, none of which would offhand seem to be very difficult, but which have already consumed over two years of work and the end is not yet in sight. These are (1) the behavior of elevated water-tanks when subjected to earthquake-motions, (2) the development of a quake-resistant design for such structures, (3) the development of a machine for reproducing actual earthquake-motions.

The first problem was begun by the model-method, using simple harmonic motion for simulating the motion of an earthquake. While some valuable results were obtained in this way, it was all too apparent that such data, however, precise, are still not truly quantitative because earthquakes are not simple harmonic in character.

The results of these studies did, however, suggest a radically different type of anti-seismic design for elevated tank-structures and some simple harmonic-motion studies were made on a model embodying the new principle. Briefly, the new design is provided with a wide range of safe deflection and also with damping action to kill building-up effects. At the same time, the structure is quite rigid against ordinary wind-force. Unfortunately, the new design is highly non-linear and, beyond a few preliminary simple harmonic-motion tests, it was considered idle to go farther with such crude approximations of earthquake-motions.

Accordingly, the next step was to design and build a machine for reproducing the actual irregular motion of earthquakes. A study was made of many possible schemes before the new machine was designed, and the advantages and drawbacks of each were carefully weighed. The new earthquake-machine at Massachusetts Institute of Technology is still in its infancy. In fact, as soon as it was considered satisfactory for the purpose, it was immediately put to work on a continuation of the model-studies of elevated water-tanks. It is estimated that there are several more months of development-work to be done on the machine before it can be said to have reached its full efficiency.

Studies of the behavior of elevated water-tanks when subjected to actual earthquake motion as recorded March 10, 1933, in Los Angeles, showed that the new design has a factor of safety of at least two over the standard structure (reinforced for a ten per cent gravity side-loading). The indications are that present design-methods are not adequate and do not rest upon a rational basis.

Although there is a need for an extended study of the new design, the most important question now to be answered is economic. So far as the tank-structures themselves are concerned, it probably would not pay in the long run to make provisions against earthquakes. It is only when the elevated water-supply forms a vital part of a fire-protection system, or when it protects the health of the community, that it is worth spending a considerable amount of money reinforc-

ing the tower. How much expenditure is justified is a question now being considered by the underwriters of fire and earthquake insurance and by other interested parties. The engineering problem is already fairly well solved.

Massachusetts Institute of Technology,
Cambridge, Massachusetts

IMPROVEMENTS IN STRONG-MOTION SEISMOGRAPHIC EQUIPMENT

R. E. Gebhardt

In 1931 the United States Coast and Geodetic Survey began an extensive program of investigation of strong seismic motions. The program has been carried on continuously since that time, and as a result of a vast amount of field-work and the accumulation of records a number of changes have been made for the purpose of improving the performance of the instruments. Other changes have been made necessary because of the more exacting requirements of the staff at the office concerned with the reduction of the records.

Of the changes made during the past year, the most important one has been the installation of double-magnification vanes on the twelve-inch accelerographs. These vanes have been installed in order to guard against loss of record during a strong shock and to aid in the interpretation of the grams. The original mirror was not disturbed but a second one was placed on the axis of rotation of the vane. The angle of inclination of the second mirror being variable makes it possible to adjust the lower magnification over a fairly wide range. For normal use this mirror is set so that its magnification is approximately one-seventh that of the regular mirror. The

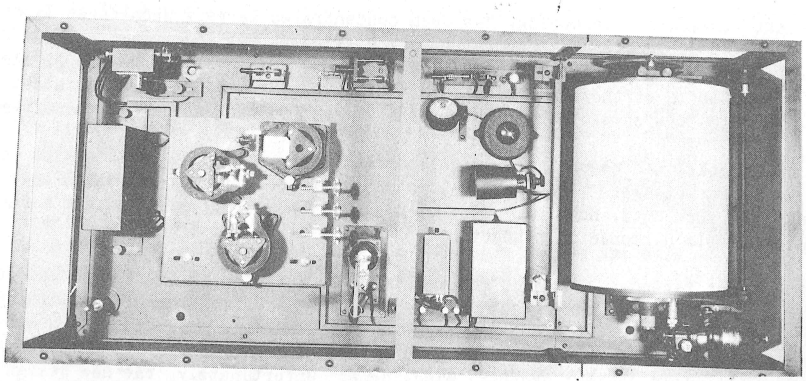

FIG. 1—BASE-LINE-MIRROR HOLDERS MOUNTED ON BASE-PLATE OF 12-INCH ACCELEROGRAPH

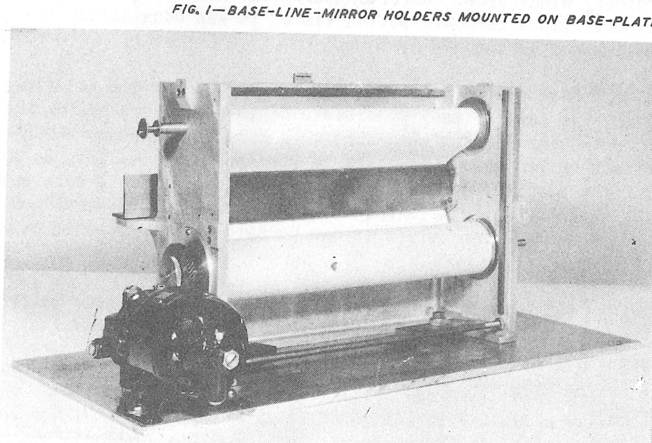

FIG. 2—RECORDER USED ON MONTANA ACCELEROGRAPHS

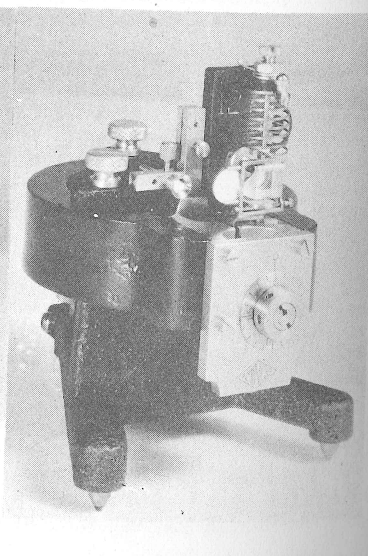

FIG. 3—ACCELEROMETER DESIGNED FOR THE MONTANA ACCELEROGRAPHS WITH SLIDING MAGNETIC-SHUNT, DOUBLE-MAGNIFICATION VANE, AND BASE-LINE-MIRROR MOUNTED ON ACCELEROMETER-BRACKET

two light-beams are brought out at the same height by the use of a small right-angle prism, thus eliminating parallax between the two spots.

A second improvement has been the installation of a sliding magnetic shunt, operating on a rack-and-pinion arrangement, which varies the damping ratio over a range from 5:1 to about 30:1. The damping of course depends largely on the strength of the cobalt-steel magnet but these magnets can be adjusted approximately to the same value.

The third important improvement has been the addition of a base-line to the record to facilitate the interpretation. The base-line serves as a reference-line to eliminate any relative motion of the drum and the accelerometer-bracket that might be caused by warping or torsional strains in the base-plate of the instrument. The only way these mirrors could be installed on the instruments already in operation was to place them along the front edge of the base-plate, slightly lower than the accelerometer-mirrors. This causes a little parallax between the two spots; while this feature is not desirable, it is not serious (see Fig. 1).

During the past few months, interest in the Montana Region has been responsible for the construction of several accelerographs in the Instrument Division of the United States Coast and Geodetic Survey. As these instruments are now under construction, it was possible to incorporate several changes and improvements that are not possible on the instruments in operation. A new-style tape-device has been developed to accommodate a paper tape 12 inches wide, and up to 400 inches long. The preliminary tests with this recorder have been very satisfactory, showing no uneven motion of the paper (see Fig. 2).

The base-line mirror has been changed to the bracket of each accelerometer. This completely eliminates the parallax that was present with the first mirrors described above. The new installation is adjustable in azimuth and in inclination, and is so constructed that the mirror may be diaphragmed readily (see Fig. 3).

Another addition to these accelerographs is a starter to respond to vertical impulses. The steady mass will pivot about a single flat spring and the mass (about one-half pound) will be balanced by a vertical spring.

In closing it should be stated that everything possible is being done to improve the quality of the records obtained from the strong-motion instruments.

U. S. Coast and Geodetic Survey,
Washington, D. C.

SAND-CRATERS AND THEIR POSSIBLE SIGNIFICANCE

P. O. Macqueen

1. It is the purpose of this paper to explain the laboratory-method in which "sand-craters" are made to occur and to point out some of the possible conclusions which may be drawn from this relatively simple experiment. N. H. Heck, Chief of the Division of Terrestrial Magnetism, United States Coast and Geodetic Survey, has joined with me in this discussion and has advised me of several important comparisons. Perhaps, however, the subject has already been published and the fact will be quickly brought to our attention. In any event we have not seen it in print and we wish at this time to submit it to criticism in order to bring out the true conclusions, if possible.

2. "Sand-craters" or sand-rings, as they might be called, are observed under certain conditions in nature where an upward jet of water passes through a bed of submerged sand such as might occur on a very small scale in the case of a spring with a fine, clear sandy bottom. In this case the action of the vertical water-currents through the sand cause small craters or rings of sand to form on the bottom of the spring and these rings have the appearance of minute flat volcanic craters. Due to the fact, however, that the surface is submerged, the sand ejected by the jet is conveyed a short distance away from the center of jet and deposited in a ring or circle around the center of the disturbance. These rings, however, have a flat saucer-like shape and are decidedly different from the normal volcanic crater-shape as explained later.

3. My first experience with sand-craters was in connection with the large slow sand water-filtration plant for Washington, D. C. I was in charge of this plant at the time and was engaged one day in the inspection of one of the filters which had just been cleaned and which was

being put back into service. The customary method of doing this is to first allow the water from the filtered-water reservoir to reverse its flow up through the clean sand until a depth of several inches above the sand is obtained. The water in this particular filter was just in the process of bubbling up through the sand in many places and I was astonished to see that each little water-bubble in the sand was in the center of a small shallow crater about four inches in diameter and one inch deep. These sand-craters were obviously the result of the upward flow of water through the sand. The most interesting thing about these formations to me at the time was that each crater was a perfect circle and that the circumferential ridges were of uniform height. I watched them form for some time and then decided to make some laboratory-experiments with these sand-craters.

4. The laboratory-method of performing this experiment is very simple. A watertight box of any convenient size such as three feet square and three feet deep is first obtained and filled to within about four inches of the top with fine clean sand. Next a water-jet consisting of a small bent pipe is embedded in the sand in the center of the box with the orifice of the pipe about six inches below the sand surface. This pipe is connected to the water-supply with a small hand-valve near the box so that the flow of water may be easily varied. A waste pipe should also be provided on one of the upper edges of the box so as to provide for a suitable overflow. The box may now be filled with water to a depth of several inches above the sand which should be smooth and level and the experiment may be started. General arrangements are shown in Figure 1.

5. By opening the valve slowly a small amount of water is allowed to flow up through the sand from the pipe-orifice and the ejected sand immediately forms a small circle around the center of water-disturbance. This sand-circle soon builds up to a height of about one inch and the diameter and height of the circle become fixed for the flow of water used. With a little experimental work "sand-craters" of various diameters and heights can easily be formed. The dimensions of the "sand-craters" are changed by the velocity of flow, the depth of water above the sand, and the depth of the pipe-orifice below the sand. The larger circles occur as may be expected with the higher velocities. It is interesting to observe the suddenness with which the craters occur, the perfect shape of the rings, and the sharpness of the circular edges. Figures 2 and 3 from photographs which were taken by James McQueen, Civil Engineer, show the general shape of the "sand-craters." Secondary rings of sand occur outside of the principal ring as shown in Figure 2, but these are always much smaller than the principal ring.

6. The explanation for these phenomena is simple and obviously it is the result of the circular wave-action radiating out from the water-bubble. The water-jet pushes the fine sand up from the center and the circular wave deposits the sand at a uniform distance from the center of disturbance. The exact mechanics of these rings involving the peculiar sharp-crested shape of the circular edges is much more complicated. The secondary rings are hidden by the principal ring and remain much lower in height. The laboratory-experiments are made with small "sand-

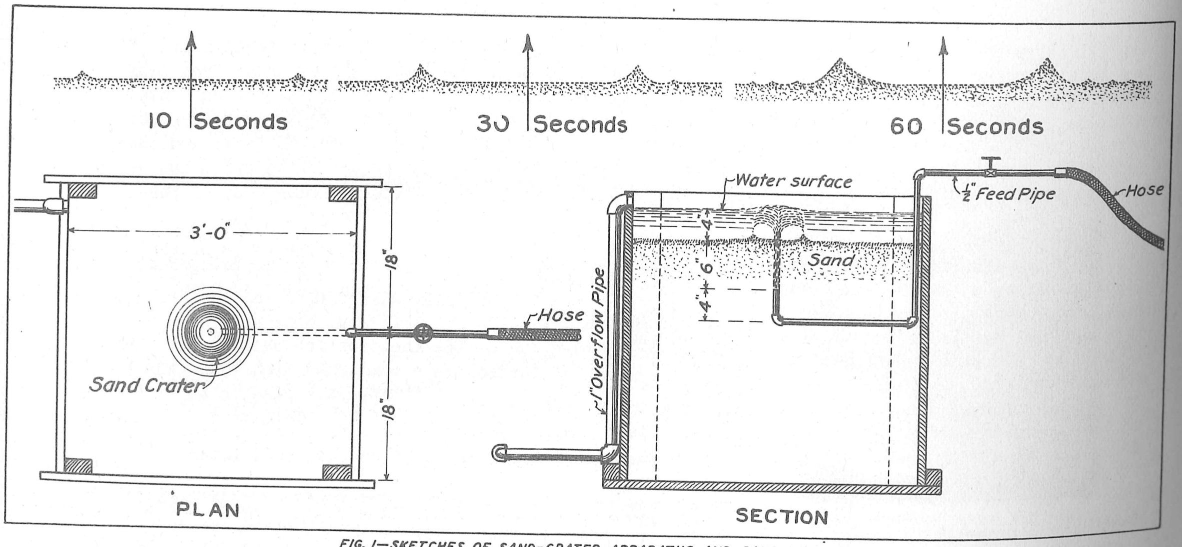

FIG. 1—SKETCHES OF SAND-CRATER APPARATUS AND SAND-CRATERS

FIG. 2—SIX-INCH SAND-CRATER—CAMERA WITH 45°-ANGLE EXPOSURE

FIG. 3—EXPERIMENTAL APPARATUS FOR SAND-CRATERS

craters" of from six to twelve inches in diameter but it is readily possible to assume that "sand-craters" of from six to twelve feet in diameter would be formed by much larger water-jets and thicker sand-deposits. Using the ratios of sand- and water-depths as determined by the small-scale experiments we may assume in a general way that a "sand-crater" as much as twelve feet in diameter would be formed with water about two feet deep, sand about four feet deep, and a large subsurface jet of water at least six inches in diameter. It would be very interesting to perform the sand-crater experiments on a large scale and determine whether it would be feasible to obtain large craters such as this in the laboratory.

7. The step from the small 12-inch diameter "sand-craters" to the large 12-foot diameter "sand-craters" is one which is relatively easy for our imagination to take but the question which follows next is far less obvious and one which involves considerable doubt. We may ask naturally if it would be possible for a condition to occur in nature which would cause a crater of sand or other material as great as 1000 feet or even many miles in diameter but it is hardly possible to assume the conditions on the Earth under which they would occur without resource to volcanic eruptions in which the disturbance would be caused by jets of hot water, gas, steam, or lava. The most important significance of these small laboratory-model "sand-craters" is their striking similarity to the volcanic craters on the surface of the moon and this comparison will be discussed first. Thousands of clear-cut photographs of the moon-craters are easily available and a few are pictured in Figure 4 for comparison. The main features of this striking similarity of the moon-craters to these small laboratory "sand-craters" are the true circular shapes of the crater rings, the flat saucer-like shape of the craters, the uniform height and sharpness of the crater-rims, and their equal elevation above the inside and outside of the crater.

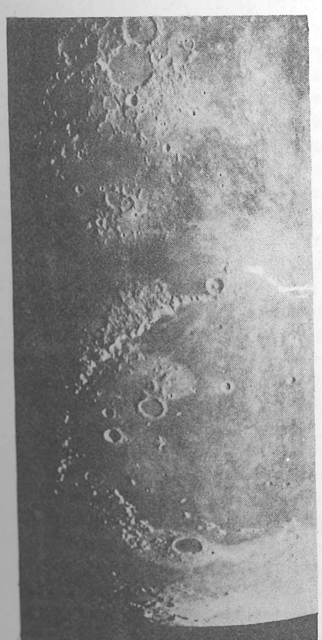

FIG. 4—THE LUNAR APENNINES AND CRATERS

8. Astronomers have noted the peculiar shape of the moon-craters for many years but even at this time they are not in agreement as to exactly how they were formed in the past ages. Various theories have been presented but none have been universally accepted. One of the theories frequently expressed is that the surface of the moon was bombarded with thousands of meteors while the surface was still partly plastic and that the craters were caused by this bombardment. This theory is open to many criticisms, the main one being that such a bombardment could not by any possible means cause the true circular-shape craters which we can readily see with the telescope. Another criticism to this theory is that the Earth itself would have been subjected to this same meteoric bombardment and we have evidence that this

did not occur. The meteoric theory of the origin of lunar craters is not considered as being one which can be readily accepted.

9. A second theory of the manner in which the moon-craters were formed is that they occurred in much the same manner as the volcanic craters are now occurring on this Earth. Here again this theory is faced with the sharpest of criticism as the moon-craters are in general entirely different in shape to the volcanic craters on the Earth. The lunar craters are flat saucer-shaped rings from five to fifty miles in diameter with uniform rims whereas the typical earth-crater is a deep irregularly shaped depression at the top of high cone-shaped mountain. This difference is so marked that the second theory of the formation of the moon-craters is not generally accepted any more than the first one mentioned. Small sand-models of the formation of volcanic earth-craters are frequently made in laboratories by blowing a current of air up through dry loose sand and the resulting cone-shaped craters are quite similar to the typical volcanic craters on the Earth, such as Vesuvius or Fujiyama.

10. The third theory given for the origin of lunar craters is that they were caused by the bubbling up of gas to the surface of the moon while it was still in a partly plastic state. These immense bubbles were assumed to break and the central portion to fall back leaving a ring of material. This process may have been repeated many times resulting eventually in immense circular-shaped craters. The lunar plains or seas were then assumed to be caused by molten lava escaping from volcanic jets.

11. The fourth theory is that the lunar craters may have been formed by emission of molten lava from vents in the moon's crust, due to the tidal force of the Earth on subsurface lava-pockets on the moon. This molten material may have been alternately pulled out and then drawn back by the tidal forces and it is possible that rings of material may have been left after each period of lava-emission. These rings may have been gradually built up by these pulsating lava-emissions with the large circular craters as the final result.

12. Each of these theories has been discussed many times by astronomers but there has not as yet been any agreement as to which theory is the most logical. The striking similarity of the small laboratory "sand-craters" described in this paper to the lunar craters has been mentioned and it is possible to develop a new theory of the origin of lunar craters on the basis of this comparison. In order to attempt this comparison it is necessary to review present conditions on the moon's surface and draw a picture if possible of another way in which these thousands of circular moon-craters could have been formed.

13. In its present condition the moon is known to be an entirely dead planet without air, vegetation, water, ice, or internal heat, and its surface is generally assumed to be a loose, porous lava-formation. There are no winds or air-currents and the all-moon craters and other formations retain their sharpness of outline indefinitely. The force of gravity is only about one-sixth as strong as here on the Earth, and the effect of forces on the moon would therefore be far greater. In the past ages the moon was intensely hot and gradually cooled off so that we may assume that at one time its surface was covered with molten lava. This surface layer may have cooled off first to a great depth and the steam and other gases may have condensed and changed to a fluid to a depth of many thousand feet, leaving the center of the moon still intensely hot. Contraction and still further cooling of the moon's surface would cause volcanic emissions of gas or lava below the surface of the fluid and these eruptions may have caused the thousands of circular craters on the moon's surface in very much the same manner that the small laboratory "sand-craters" were formed. The striking similarity of the saucer-shaped model sand-craters with the present moon-craters has been mentioned. Instead of sand, however, the material in the case of lunar craters would be large and small pieces of lava which would become solidified after emission from the central jet. Due to the difference of gravitational force on the moon and the relatively high transporting power of a fluid which varies from the third to the sixth power of the velocity it is possible that this ejected material would be carried to a great distance from the center of disturbance and deposited under the surface of the fluid in a ring from five to fifty miles in diameter depending upon the force of the central jet.

14. To continue the picture, however, we must explain, if possible, the disappearance of the fluid from the moon's surface and we will have to assume that it was gradually lost into space due to weakness of the moon's gravitational force or that with the ultimate cooling of the moon it was gradually absorbed into enormous voids in the moon's center. It is possible, of course, to draw other mental pictures of the formation of these moon-craters by assuming eruptions through very thin molten lava as the fluid-cover but the one presented appears to be the easiest to visualize.

15. As a possible important point of significance of the experimental laboratory "sand-craters" the conclusion is here offered that lunar craters may have been originally formed by submarine volcanic action and that they possibly occurred in the manner described in the preceding paragraphs.

16. To come back to the Earth again, however, the question is raised as to whether the model "sand-craters" have any significance as far as earth-formations are concerned. Some study has been given to this question and with one possible exception there do not appear to be any large-scale earth-formations which have a definite resemblance to the model "sand-craters." Volcanic formations on the Earth are the result of eruptions of lava or cinders in free air and the cones are hence entirely different. Some few earth-craters such as Mauna Loa and Crater Lake have approximately circular shapes but they fall far short of being like the clear-cut, saucer-shaped laboratory "sand-craters." Earthquake-emission of mud and sand have been observed but these also fail decidedly to resemble the "sand-crater" models. The well-known large meteor-crater in Arizona, which has been described in detail by Dr. Clyde Fisher, is different in origin entirely.

17. The single known possible exception mentioned above is the very interesting formation known as the Carolina "Bays" which have been described by F. A. Melton and William Shriever in the Journal of Geology in 1933. The authors give complete descriptions of these large rings or bays near the coast of South Carolina which are from half a mile to a mile in diameter and suggest as the most logical hypothesis of origin that they are the result of meteorite scars. The semi-elliptical shape of the craters and other facts seem to make this hypothesis a very logical explanation.

18. It is possible, however, to visualize a manner in which these Carolina "Bays" could have been formed in practically the same manner that the small laboratory "sand-craters" were formed and to do this we again attempt to build up a series of conditions which might lead to this origin. We know that at one time this region was under water and possibly subjected to strong tidal currents of a fixed direction. We may also assume that volcanic emissions of gases or hot water might have caused many large centers of disturbance in this vicinity. These conditions, together with the sandy soil would possibly be the cause of these large shallow elliptic craters. The extremely low height of the rims would have to be explained by extensive subsequent silting action. The double and triple rims in the case of some of the Carolina "Bays" agree also in general with the smaller secondary sand rings which occur with the laboratory "sand-craters." It is realized that this hypothesis of origin of the Carolina "Bays" is subject to many criticisms but it is offered as another possible explanation of these interesting and unique formations.

19. In conclusion the statement is again made that this simple laboratory method of making "sand-craters" may have been presented by other writers, and if this is the case apologies are offered for not mentioning their names. The similarity of these "sand-craters" with respect to lunar craters is considered as quite important and definite although the conditions surrounding the origin of the lunar craters may have varied to some extent from the method presented in this paper. It is suggested if possible that experiments with "sand-craters" be continued on a much larger and more complete scale than described in this paper as the comparisons will surely be found to be both interesting and valuable to the science of geology and astronomy.

Corps of Engineers,
United States Army,
Washington, D. C.

A GENETIC SYSTEM OF EARTHQUAKE-ORIGIN

H. Landsberg

Seismology has moved in recent years into the foreground of geological research. The contacts between the two scientific fields are numerous and important as recently demonstrated by Macelwane [see 1 under section "References" at end of paper]. While structural geology could get reliable data from the seismological records, dynamic geology has been benefited with comparatively few facts. We have, however, to visualize that the earthquakes are evidence of acting geological forces. Although all geological events are customarily gaged in a scale of millions of years, it may be stated that the slow and imperceptible, mostly even unmeasurable, geological process culminates frequently in earthquakes which are events accessible to observation--sometimes too fatally obvious.

One may raise the question as to what place in the system of dynamic geology the earthquakes really belong, principally as the occurrence of certain types of earthquakes have been used as an argument for or against geologic theories, especially in the case of deep-focus quakes as related to the theory of isostasy [2, 3]. In the first place it has to be realized that earthquakes are of widely different origin but in the past seismologists have simplified the issue by classifying only three general categories, which Sieberg [4] as main authority gave as tectonic, volcanic, and cave-in earthquakes. The detection of the deep-focus earthquakes has already brought some confusion into this simple system because instead of a cause there is now a more seismometrical fact introduced as a significant feature. From the seismologist's viewpoint even the secondary reasons for earthquakes, the numerous trigger-forces, which release the accumulated stresses might serve as a basis for classification. If we accept Macelwane's [1] statement that the causes of earthquakes are still a wide-open problem it seems to be a bold attempt to classify them at all. Nevertheless, a certain grouping of the events, even if preliminary, incomplete, and challengeable in detail, may help to clarify and to bring some order into the observations. For this matter seismology may take advantage of geological conceptions with the necessary reservatio mentalis as regards some contested theories in this field.

One fact may be regarded as generally accepted, namely, that there exist on the Earth two types of zones according to their geological behavior, one where the acting forces are extremely slow, where major geological upheavals have not happened for a long period, and others, where relatively fast motions and changes in structure are to be observed. Side by side we have motions of orogenic and of epirogenic type. The motions observable in the crystalline crust of the Earth are due to causes which, at least partly, have their origin in the elastico-viscous substratum, to use the terms of Daly [5]. So far as the participation of this lower layer in making geological history is concerned, it seems to be differentiated also according to the two zones. In the orogenic zones it plays an active part, while in the epirogenic zone it seems to be mainly passive. The subcrustal activity in the zone of mountain-building, whether we call them subcrustal currents in the sense of Ampferer [6] and Schwinner [7] or thermal convection as Holmes [8] puts it, is witnessed by the deep-focus earthquakes which indicate changes and motion. It is irrelevant for our present deliberations to what we attribute these motions. Volcanic activity is another sign of these zones and in the outer crust we find horizontal movements as one of the characteristic features accompanying the mountain-formation. On the other hand, there is no indication of any active motion in the subcrustal material in the epirogenic consolidated areas; there are no appreciable horizontal movements to be observed, while vertical motions are prevailing. This latter type might be attributed to isostatic adjustment. The theory of isostasy is still so largely contested that our statements concerning it have to be carefully weighed. It is generally accepted that we have a specific light crustal material floating on a specific heavier one. This fact would mean even if we deal with solids that changes in mass-distribution in the upper part will tend to become gravitationally compensated in a rotating body like the Earth. The only open question is at what rate this adjustment would take place. As the subcrustal material will be highly viscous in any case there has to be an appreciable lag in the compensation-movement so that we may say isostatic equilibrium is merely the final, so to say, ideal state. The ever-working and fast-working dynamic forces, erosion and sedimentation, change the outer crust and the isostatic adjustment tries slowly to balance their effects. This will work fairly well if the subcrustal material itself is at rest. As soon as it is itself in motion, the forces which produce this motion will tend to obscure or even prevent isostatic adjustments. Therefore, since we had to assume an active part of the subcrustal material in orogenic zones, isostasy will be of minor importance until the zone gets to rest. This is quite in accordance with statements made by R. T. Chamberlin [9] regarding isostasy. It accounts perhaps also for the findings of Dahm emphasized by Macelwane [1] that seismometrical data show horizontal differences in the subcrustal material. This, however, does not exclude isostatic adjustments between old blocks and their heavier underlying subcrustal material. We get therefore a scheme which is represented in Table 1. It remains now to be seen how the different observed

Table 1

Agent	Orogenic zone	Epirogenic zone
Subcrustal material	Active	Passive
Crustal motions	Every direction	Vertical
Total movement	Kinetic	Isostatic
Earthquakes	Crustal and subcrustal	Crustal

types of earthquakes fit into such a dualistic scheme. In the first place, we have to single out the cave-in earthquakes which disregard the zonal differences; they may happen everywhere, provided there exists any hollow space in the crustal zone. According to our present knowledge they are negligible in number compared with the total number of earthquakes, are weak in effects, and are principally observed in regions where larger layers or deposits of water-soluble material are present.

In the epirogenic zone we observe two types of earthquakes which are both to be explained by the upward and downward adjustment-movements. They are frequent in places where we have differential movement of two blocks side by side. The opposing directed forces accumulate stresses which are released along planes of weakness as represented by old faults -- faulting-quakes are the result. Besides these, new break-lines may develop and rupture-quakes will occur. The faulting quakes are usually single events, in many cases not even producing aftershocks while the rupture-quakes have the tendency of happening in whole showers or swarms. The focal depth of both types usually does not exceed 30 to 50 km and is in many cases even closer to the surface. The relationship between vertical motions of isostatic type and earthquakes has been well demonstrated in the cases of Scandinavia, France, and Germany [10].

In the zones of mountain-formation the active participation of the subcrustal material gives reason for other kinds of earthquakes. Here are the localities where the deep-focus earthquakes are observed. We do not have sufficient evidence to formulate a conception implying faulting or similar motion as reason for these quakes. At the present it seems more likely that either phase-change in the physico-chemical sense or recrystallization is responsible for this type of quakes. This needs not to be an explosive event if the subcrustal material has only a fair amount of rigidity, which is probably the case. Then the physical or chemical change may take place over a longer period of time, creating inhomogeneities which may be even larger hollow spaces in case of volume-decrease or high pressures in case of volume-increase. In a rigid material such stresses will be released much in the same way as in surface quakes by secondary forces. Such a conception would make it easier to account for certain observed periodicities of the deep-focus quakes and also account for the fact of repetitions from certain foci, if the stresses are only partly released.

Next and also characteristic for the orogenic regions are earthquakes connected with volcanic activity. The first type, namely, eruption-quakes needs no special discussion as they do not differ from vibrations produced by any kind of explosion. Furthermore there exist earthquakes closely associated with volcanism, originating in deeper layers of the crust, although not much about their exact mechanism is known. Branca [11] connected them with intrusions and pending further verification we may at least tentatively reserve some space for them in the scheme. Finally there remain the earthquakes which are the most important from our human viewpoint, due to their violence, the great tectonic earthquakes of the zone of mountain-building. There again we have block-movements but this time due to the forces of mountain-formation, bulging and buckling the crust. The resulting stresses are consequently larger than the moderate ones, which we observe in the epirogenic zones. The restoration of a state free of stress is more difficult; the adjustments go on for a longer period as evidenced by the numerous aftershocks of each major earthquake. These quakes may be termed as orotectonic earthquakes. Thus we get the picture of Table 2.

Table 2

Zone	Type of quake	Depth in km	Character	Cause
Epirogenic	Cave-in		Weak	Lack of support
	Faulting	0-50	Single, moderate shock	Isostatic movements
	Rupture	0-50	Swarm of moderate shocks	Isostatic movements
Orogenic	Cave-in		Weak	Lack of support
	Deep-focus	100-1000	Moderate on surface	Physico-chemical change?
	Eruptive	0-10	Weak	Explosion
	Intrusive	10-50	(?)	Magmatic changes?
	Orotectonic	10-50	Destructive with many aftershocks	Mountain-formation

Finally it seems to be worth while to call attention to the interaction of different earthquake-types. Adjustments at one place may release shocks elsewhere -- a phenomenon usually called resonance. Equally important are reactions which have a longer lag in time. If the deeper layers are disturbed it cannot be helped that the upper layers are affected too. If one end of a block is moved the other will have to come to a new equilibrium-position as well. It can be shown that earthquakes themselves condition other earthquakes, which are not simply aftershocks and this angle should be considered in the future.

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Geophysical Laboratory,
School of Mineral Industries,
State College, Pennsylvania

RELATION OF EARTHQUAKE-BELTS OF THE PACIFIC AND INDIAN OCEANS TO SUBMARINE TOPOGRAPHY

N. H. Heck

It has often been pointed out that earthquakes are chiefly associated with mountain-building and with deep ocean-troughs. This is quite true when applied to the greater portion of the two major earthquake-belts and especially in the case of the major earthquakes.

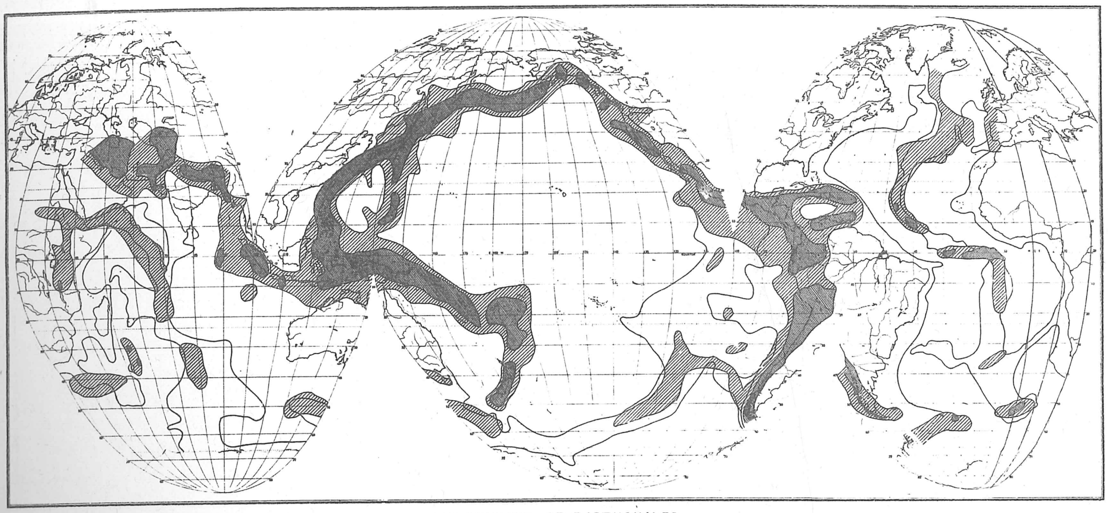
However, the Mid-Atlantic Ridge is a definite exception. In The origin of the Mid-Atlantic Ridge, by Henry S. Washington (Maryland Acad. Sci., v. 1, no. 1, 1930) it is stated that the Ridge is a submerged mountain-ridge of a type different from any other on the Earth. In general it is less than 12,000 feet beneath the sea with some parts less than 9000 and with a few volcanic islands rising 3000 to 4000 feet above the sea. Its general height above the surrounding ocean-floor is between 3000 and 6000 feet with a few island-peaks rising 18,000 to 20,000 feet.

There is little known evidence of the existence of deep troughs in the vicinity of the Ridge. There are a few deep soundings in the region of the equator where the greatest seismic activity occurs but the soundings are too few to indicate whether or not troughs exist. In any case the earthquakes are associated with a rise or Schwelle.

There has been some question whether there is similar association with rises in other oceans. The author pointed out this possibility as regards the Indian Ocean in his article "A new map of earthquake-distribution" in the Geographical Review for January, 1935 (p. 128). Such an investigation would have been useless a short time ago because of lack of information about the submarine contours. As an example of this, H. Rehm in a recent article (Die Erdbebentätigkeit der Weltmeere Sowie Ihre Beziehungen zur Tektonik) has the Schwellen or rises outlined in such a general way that the significance is not brought out.

In 1935 Dr. G. Schott included in his book on "Geographie des Indischen und Stillen Ozeans" a map in colors which gives through certain contours the depth of the Pacific and Indian Oceans according to the latest available information. He adopted 4000 meters as boundary between the Schwellen and the ocean-bed. The earthquake-information from Rehm's map was plotted on this (see Fig. 1) and it was at once seen that there is a definite relation between depth and general earthquake occurence, which in part has not heretofore been brought out for these oceans.

The plotting of the major belts brought out no new information of special interest since the features they are associatied with are well known. However, in the branches of the belts and detached areas, both of which have very few major earthquakes, there appears a very definite relation between rises as defined by the 4000-meter curve and earthquake-occurrence. It will be seen that nearly all of the activity is confined to the rises. This does not mean that there has been earthquake activity over all the area of the rises. The nature of the available data should not be forgotten. There are many earthquakes listed in the International Seismological Summary which cannot be located and some of these may be in these areas. The distribution of seismograph-stations is not well suited for locating the lesser earthquakes of these regions. The total period of determination of submarine earthquakes is not in excess of 25 years and many of the determinations have



DISTRIBUTION OF EARTHQUAKES
[HEAVY CROSS-HATCHING INDICATES MAJOR EARTHQUAKES RECORDED THROUGHOUT THE EARTH; LIGHT CROSS-HATCHING INDICATES ALL OTHER EARTHQUAKES WIDELY RECORDED ON INSTRUMENTS; CONTINUOUS LINE BOUNDS AREAS WITH DEPTH LESS THAN 4000 METERS]

been only partly satisfactory. The surprising fact is that there is such definite correlation.

In only one case does there seem to be an important area in a region indicated as a deep though in this case there is a rise very near. This is a small but active area southeast of Madagascar. It is possible that further soundings might develop either a rise or a deep ocean-trough and perhaps more likely the latter.

There are a number of scattering earthquakes not shown since only those occurring in groups have been placed on the map. The number is not large. Some of these occur in the deep basins. It should be understood that there is no intention to deny the occurrence of earthquakes in depths greater than 4000 meters except in the deep troughs but to point out the tendency against such occurrence.

No attempt will be made to discuss the geological significance. It is of interest to point out that this comparison could have been made only within the past few months, for the complete information needed was not available in usable form.

U. S. Coast and Geodetic Survey,
Washington, D. C.

REVIEW OF EARTHQUAKES FOR THE PAST YEAR

E. W. Eickelberg

It is rather difficult to compile accurate statistics in April for the period of twelve months ending March 31, 1936. We can give the number of epicenters determined by the Jesuit Seismological Association and the U. S. Coast and Geodetic Survey in cooperation with Science Service and numerous universities and others, but this does not include the whole mass of information collected by agencies in other countries but not yet available. All disastrous earthquakes are not world-shakers and, therefore, many important earthquakes occur whose epicenters are not determined by agencies in the United States.

The average number of immediate epicenters determined by the U. S. Coast and Geodetic Survey and Jesuit Seismological Association in cooperation with Science Service for the past four years is 58, whereas in the past year there were only 23. On the other hand, 50,000 people were killed during the present year as compared to 130 in the preceding year, showing that earthquake-statistics for any one year are meaningless except to show that there is wide range in their number, severity, and destructiveness.

Dr. Charles Davison in a recent article in Nature (v. 137, p. 605, 1936) estimates that the